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OPPORTUNITIES FOR ELECTRICALLY EFFICIENT TECHNOLOGIES: ENHANCEMENT OF CONVECTION HEAT TRANSFER IN ONTARIO INDUSTRY

Report #91-268-K

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ABSTRACT

The pumps and fans used for convection heat transfer in industry consume approximately 510 MW. There are a number of convection enhancement techniques which could be used to reduce the electricity consumption in convection heat transfer processes by 50% or more. A review of published material on convection enhancement techniques has identified promising opportunities for new demand management initiatives. The initiatives include High Flux tubing for condensers, infrasonic cooling of materials, air-jet heating or cooling of materials, and tube inserts for heat exchangers.

job	file	date	report no.
12-180	814.35	December 16, 1991	91-268-K

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EXECUTIVE SUMMARY

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B.G. Woods

Background

Convection heat transfer is widely used throughout industry. Two main application categories include materials processing and heat exchangers. It was estimated that the pumps and fans used for convection heat transfer in Ontario consume approximately 510 MW.

There are a number of enhancement techniques available which can be used for both materials processing and heat exchangers. The convection enhancement techniques will often increase the amount of heat transfer per unit of electrical power required. In many cases, the enhancement techniques can result in power savings of 50% or more.

Objective

The objective of this study was to review and summarize the applications of heat transfer enhancement techniques. Additionally, short term technology transfer, and longer term research and development opportunities were identified.

Approach

The information for this study came from literature searches and a survey of the manufacturers of convection enhancement equipment. The information was then summarized in a format consistent with previous "opportunities" studies.

Key Results

Fifteen different processes which utilize convection heat transfer enhancement techniques were identified and summarized in tabular format. From the fifteen processes, the following technology transfer, and research and development opportunities were identified.

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Technology Transfer Opportunities

- High flux tubing for ethylene column condensers in the chemical process industry.
- Infrasonic cooling or heating of plastic pellets.
- Air-jet cooling or heating of cereal products.

Research and Development Opportunities

- Infrasonic cooling of cement clinkers.
- Tube inserts for oil coolers.

Recommendations

There are a number of recommendations in the report which are highlighted below.

- Follow up the technology transfer opportunities with data verification and preparation of case studies.
- Follow up the research and development opportunities by initially involving end users.
- Assess the power requirement of air-jet impingement processes.
- Work with the manufacturer of infrasound equipment to have a small scale unit built. This will make the technology more accessible for end users.
- Look at the potential for enhancing drying processes in a similar "opportunities" report.
- Establish a working group to utilize the expertise in various branches of Ontario Hydro.

Acknowledgement

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OPPORTUNITIES FOR ELECTRICALLY EFFICIENT TECHNOLOGIES: ENHANCEMENT OF CONVECTION HEAT TRANSFER IN ONTARIO INDUSTRY

1 INTRODUCTION

The traditional technique for heating and cooling in industry involves forced convection. With forced convection, a medium such as air is blown across a material to provide high rates of heat transfer. A number of techniques are available for enhancing the heat transfer rates in convection processes. In addition to just increasing the rate of heat transfer, many of these enhancement techniques will increase the amount of heat transfer per unit of pumping or fan power. These techniques will therefore provide load reducing opportunities which can help Ontario Hydro meet its demand management targets.

1.1 Background

There is a considerable amount of information published on the performance and use of heat transfer enhancement techniques. A good review of the field was provided by Bergles /1/. In order for Ontario Hydro to take advantage of the enhancement techniques (in its energy management function), there is a need to analyze and summarize the information in a format which is useful for planning both energy management programs, and research and development projects.

The type of information needed for selecting a technique includes descriptions of the processes which could utilize the heat transfer enhancement techniques. The main criteria for selecting the heat transfer enhancement opportunity was an undeniable economic and technical benefit for the end user, and the potential for electricity savings. Other factors that were important for assessing the application include:

* Replication Potential (as a first approximation, this is taken as the number of plant sites in Ontario within the same industry classification);
* Energy and Demand Reduction;
* Environmental Benefit;

* Trade Allies (outside organizations which are involved in relevant research and development and have an interest in promoting or co-sponsoring the development of an application);

* Industry Health (eg. particular interest in fast growth industries, and industries of significant size capable of investing or compelled to invest in new technologies).

1.2 Objective

The objective of this report is to summarize the applications of techniques that enhance heat transfer, and highlight the best energy management opportunities. The opportunities are highlighted according to whether they are immediate opportunities (technology transfer) or longer term (research and development) opportunities.

The format of the information presented in this report is consistent with previous "opportunities" reports. The consistent format will help to facilitate an assessment of convection enhancement opportunities with regard to other technology opportunities.

1.3 Method of Approach

The study included the compilation of data that was readily available from equipment suppliers, distributors, and end users. Additional industry information was obtained from Statistics Canada data on Ontario manufacturers /2/. The specific information obtained from the various references includes:

* Description of the application;
* What is the traditional technology for the application?;
* What electrotechnology is used to perform the same task? What is the industrial application status of the electrotechnology?;
* What are the limitations of the electrotechnology compared to the current technology?;
* Are there unresolved problems or questions which need to be answered? What are the research and development needs?;
* Are there applications already in-place elsewhere? What are the technology transfer needs?;
* What is the potential for replication in Ontario (ie, number of similar establishments in Ontario suitable for the same application)?;
* Key references in the literature describing the application;
* Trade allies for future collaboration.

2 CONVECTION HEAT TRANSFER ENHANCEMENT APPLICATIONS

Forced convection is a common heat transfer technique used in industry (ie, as opposed to radiant or conduction techniques). The two main application categories for forced convection which this report will address are heat exchangers and materials processing. The techniques that can be used for heat exchangers will often involve surface modifications or tube inserts, whereas the techniques that can be used for materials processing will primarily modify the air flow pattern. The following section will review various aspects of enhancement applications with regard to these two categories.

2.1 Electrical Energy Used in Forced Convection Heat Transfer

In forced convection heat transfer applications, electricity is primarily used in the form of pumps, blowers and fans. Compressors are also used in heat transfer processes in the chemical industry (eg. distillation) and refrigeration.

A recent study /3/ looked at the end use of electricity in Ontario industry. It was found that fans and pumps account for 20% of the industrial consumption of electricity in Ontario. However, not all of the fan and pump load is used for forced convection. The data from the end use study was re-worked to determine the amount of pump and fan power used for forced convection heat transfer. It was found that:

- the estimated fan load for forced convection heat transfer is **370 MW**
- the estimated pump load for forced convection heat transfer is **140 MW**

- the total load used for forced convection heat transfer is **510 MW**

The fan load of 370 MW will be divided between the materials processing and heat exchanger applications, and the pump load of 140 MW will be used for heat exchangers.

2.2 Reasons for and Methods of Forced Convection

There is a wide variety of uses of forced convection heat transfer in industry. Some examples include curing plastics and coatings, cooking and chilling foods, heat treating metals, molding thermoplastic parts, chemical processing and dry cooling towers.

In materials processing applications, fans or blowers are used to provide the air flow. In many cases, the heating or cooling process will represent the process bottleneck. Increasing the heat transfer rate is commonly achieved by increasing the fan speed, or, increasing or decreasing the air temperature (for heating and cooling respectively). Heat transfer enhancement techniques can therefore provide alternate approaches for diminishing process bottlenecks as well as providing specific process benefits such as reducing the operating cost, and improving product quality.

Heat exchangers are used to some degree in practically every industry. There is a very large variety of applications for heat exchangers; some common applications include refrigeration, HVAC, and cooling towers. A number of different types of heat exchangers are used in industry, however the shell and tube is by far the most common. A recent study /12/ found that in 1982, shell and tube heat exchangers made up 77% of the heat exchanger market in sales, and 80% of the market in number of units sold. Enhancement techniques which are applicable to shell and tube heat exchangers will therefore be of particular interest.

The techniques that are available for enhancing convection heat transfer in materials processing and heat exchangers are briefly summarized below. A list of manufacturers is provided in Appendix B.

2.2.1 Techniques for Enhancing Heat Transfer in Materials Processing

i) Air Impingement

Air impingement increases heat transfer by impinging high velocity air on a surface. It is also used to create a high velocity around surfaces or particles. The air flow passes through either nozzles (air-jet) or slots (air-slot or air-knife). Air is supplied with either blowers or air compressors, however where blowers can be used, they will be more efficient than compressors. Configurations of two air jet applications are shown in Figure 1. There are a number of heat transfer applications for air impingement, however a larger use for the technology is in drying processes. Enhanced drying processes are beyond the scope of this study, but could be considered in a future study.

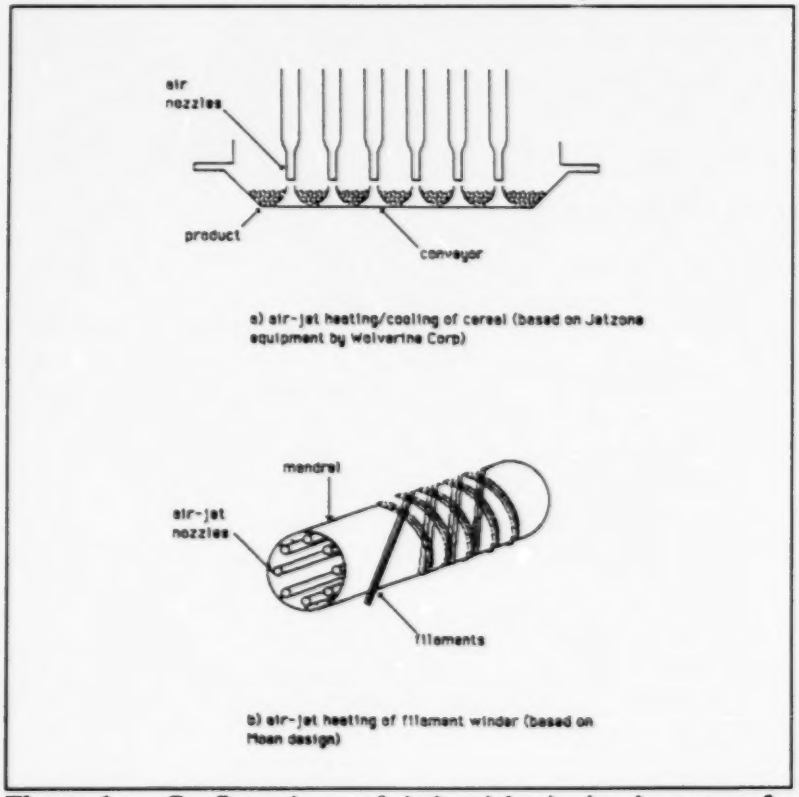

Figure 1 - Configurations of industrial air jet heat transfer applications

ii) Infrasound

Infrasound is the sub-audible range of sound frequencies (ie, less than 20 Hz). The pressure fluctuations of the infrasound are used to create an oscillating flow of air. The turbulence caused by the oscillating air flow results in a higher rate of heat transfer. To amplify the pressure oscillations and the amplitude of the oscillating velocity, infrasound systems will use resonators. An example of an industrial infrasound unit is shown in Figure 2.

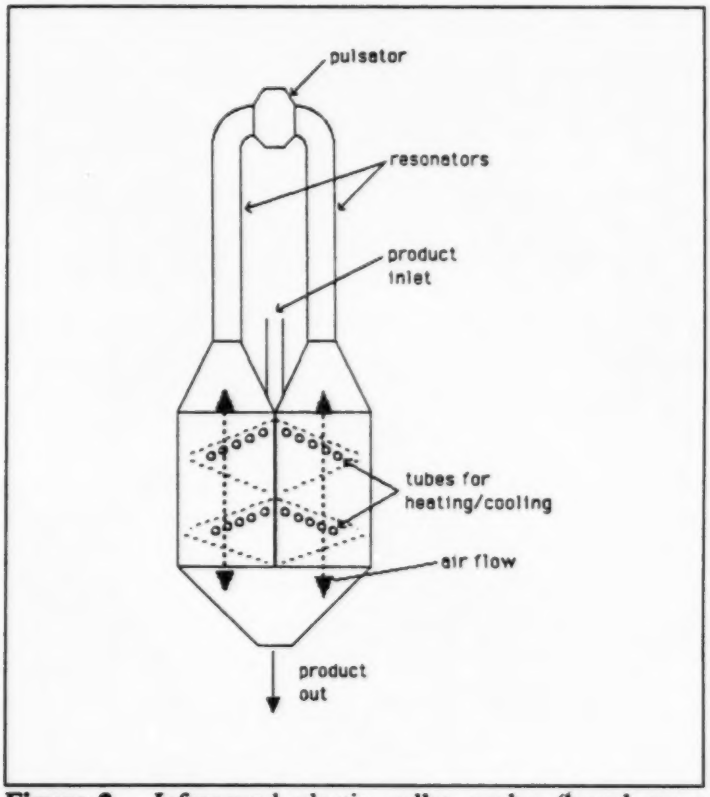

Figure 2 - Infrasound plastic pellet cooler (based on a design by Infrasonik)

2.2.2 Techniques for Enhancing Heat Transfer in Heat Exchangers

i) Treated Surfaces (Coatings)

Treated surfaces involve fine scale alterations of the surface finish or coating. They are used primarily for boiling and condensation heat transfer as the roughness height is usually too small to affect single phase heat transfer. An example of a treated surface is shown in Figure 3.

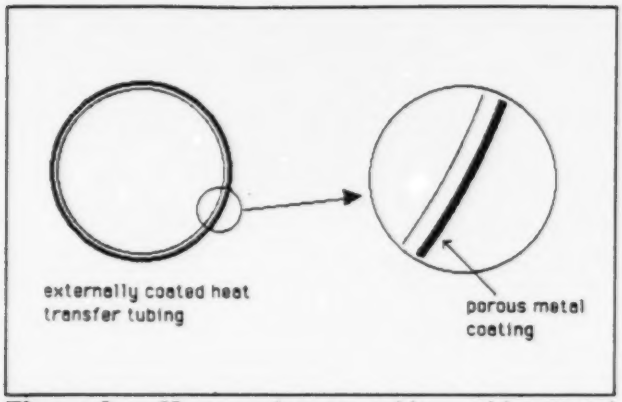

Figure 3 - Heat exchanger tubing with treated surface (based on UOP High Flux Tubing)

ii) Tube Inserts

Inserts are flow altering devices which are used in the tubes of heat exchange equipment. They increase heat transfer by creating turbulence in the tube, and therefore work best with viscous liquids (eg, chocolate, oil, etc). In addition to being designed into original heat exchanger equipment, inserts can be fitted into an existing heat exchanger to increase heat transfer. Some of the different types of inserts are shown in Figure 4.

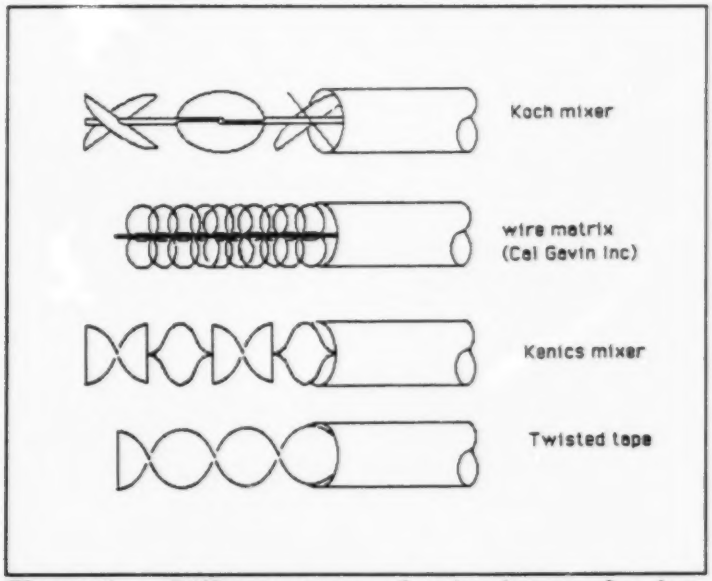

Figure 4 - Different types of tube inserts for heat exchangers.

iii) RodBaffles

In shell and tube heat exchangers, baffles are used to alter the shell-side flow, maintain the tube spacings, and also to minimize the vibrations and noise. A typical segmented baffle is shown in Figure 5. An alternative to the segmented baffle is the RodBaffle (produced by Phillips Petroleum) which uses grids of rods to maintain the tube spacing. A sketch of the RodBaffle system is shown in Figure 5.

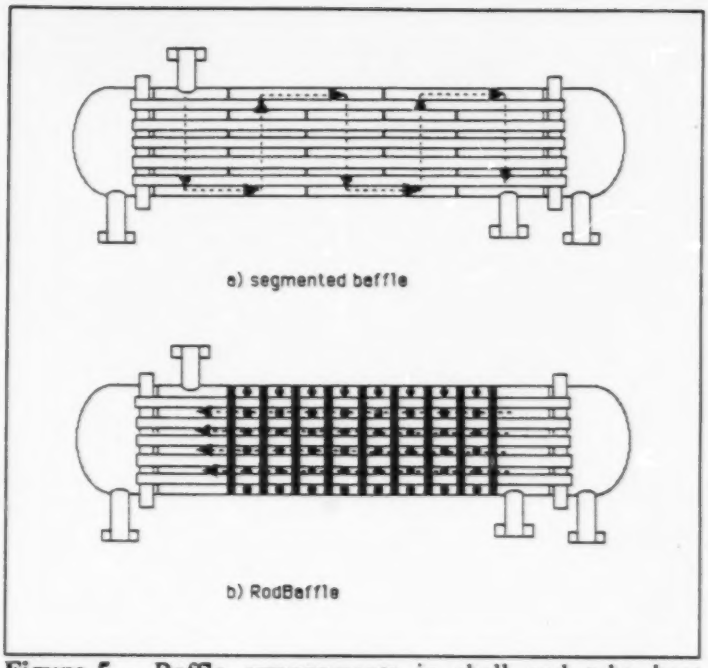

Figure 5 - Baffle arrangements in shell and tube heat exchangers.

iv) Extended Surfaces

Extended surfaces provide a way to increase the surface area for heat transfer without increasing the heat exchanger size. Since radial fins are routinely used in many heat exchangers, in this study extended surfaces refer to unique fin designs. Some examples of tubing with extended surfaces are shown in Figure 6. Although there are no applications described in Appendix A which use extended surfaces (since no specific industrial application references were available in the literature), they are presented here because they have considerable potential for industrial applications such as refrigeration and cooling towers. Also, published experimental results (referred to in /4/) have shown that a number of tube configurations will increase the amount of heat transfer per unit pumping (or blower) power.

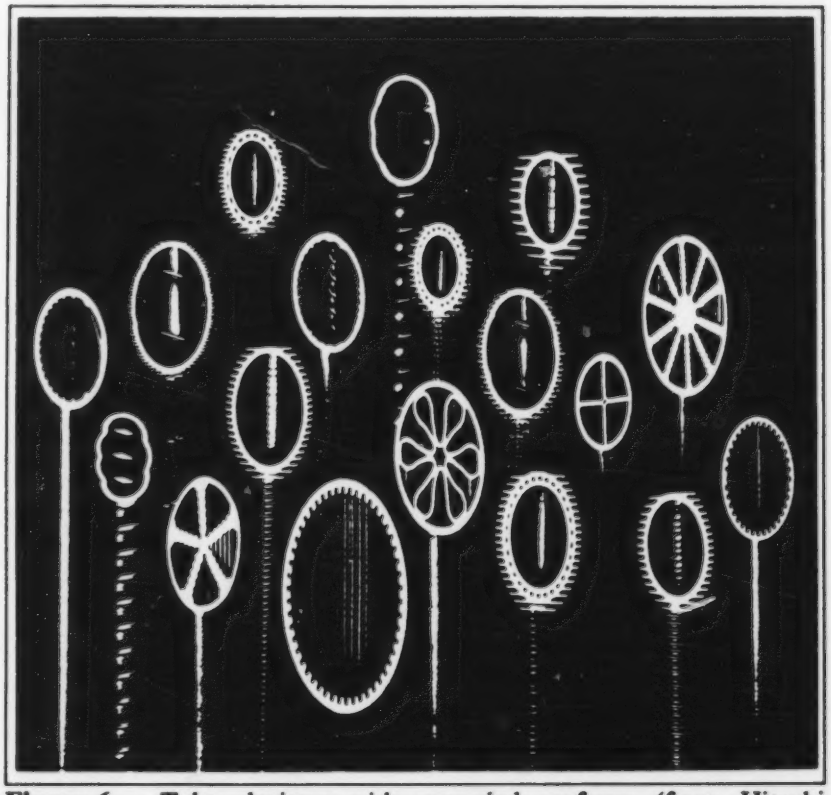

Figure 6 - Tube designs with extended surfaces (from Hitachi brochure)

2.3 Benefits of Heat Transfer Enhancement Techniques

i) *Enhancement Techniques for Materials Processing*

The benefits associated with jet impingement and slot impingement heat transfer are:

1) high heat transfer rates can be achieved;

2) the higher rate of heat transfer will allow for a more compact process;

3) the air distribution systems for impingement processes ensure a more uniform heat transfer than convection ovens.

The typical benefits to the end user of infrasound systems include:

1) A reduction in power consumption. Lab tests /5/ have shown that power savings between 20% and 50% could be achieved with infrasound, and applications of infrasound have achieved power savings of 60%. The differences between the lab and field results likely reflect the sensitivity of the power savings to the efficiency of the fan replaced.

2) Infrasound has also been shown to provide a more uniform heat transfer around cylinders in lab tests /5/ and with full scale applications involving the cooling of wire rod. The uniform cooling of steel provided a more consistent quality.

3) The exhaust air is more likely to be at a useful temperature for heat recovery since infrasound provides a higher heat transfer rate with less net air flow.

ii) *Enhancement Techniques for Heat Exchangers*

The main benefits associated with enhancement techniques for heat exchangers were summarized /6/ as:

1) reduction in heat exchanger size, and consequent capital cost savings,

2) increased heat transfer, and

3) reduction in pumping power.

In the design of any heat exchanger, there will be a trade-off between the three benefits listed above. The selection of the parameters to be optimized (eg, size, power or heat transfer) will have an important effect on the type of tubing to be used. For example, Webb states /4/ that internally finned tubes can provide pumping power reductions of 42% with a helix angle of 0°, but a helix angle of 20° can provide a pumping power reduction of 69% for the same heat transfer.

2.4 Limitations of Enhancement Techniques

In any heat transfer process, the heat must flow through a series of materials or gases which have different thermal resistances. A common limitation with any heat transfer enhancement technique is that

it should address the largest resistance to heat transfer in the process. For example, in cooling a material with air, the material will have an internal resistance to heat transfer, and the air will have another (probably different) resistance. If the material's internal resistance is much greater than the resistance in the air, then decreasing the resistance of the air will have a very small effect on the cooling rate.

Specific limitations of the various enhancement technologies are summarized below.

i) *Enhancement Techniques for Materials Processing*

It is expected that the main limitation with jet and slot impingement will be the power required to compress the air, or drive the blower. There was no data found in the literature which addressed the power requirement of impingement heat transfer, however Mujumdar /7/ estimates that impingement dryers have moderate to high energy consumptions relative to other drying techniques.

The main limitation with infrasound is that it is a relatively new technology and the conditions in which it will work best are not well defined. Also, there is a lack of small or lab scale equipment for preliminary assessment of infrasound applications. Therefore process development must currently be performed on full scale processes, which can be costly and difficult to re-configure for optimization. A small scale infrasound unit was developed at the Ontario Hydro Research Division, however the development did not include an optimization of the efficiency. The development of a small scale infrasound unit which incorporates features of the full scale units and the Ontario Hydro prototype could assist with the application of infrasound by allowing for small scale tests by the potential end users.

ii) *Enhancement Techniques for Heat Exchangers*

The biggest limitation to heat exchanger enhancement techniques is the effect they will have on the fouling rates. The enhancement techniques will have an effect on a number of parameters which contribute to the fouling rate, such as

1) fin geometry and surface roughness

2) flow velocity and flow distribution

3) surface and fluid temperature.

Unless there is sufficient evidence to indicate that an enhancement technique will not create fouling problems, industry will be reluctant to adopt the technique.

2.5 Selection of Enhancement Applications for Technology Transfer and Future Research and Development

The specific factors needed to properly assess the opportunities for heat transfer enhancement techniques were presented in section 1.1. The tables in Appendix A contain information gathered in the review of published literature and product literature. In order to avoid repetition of very similar processes, the applications in Appendix A represent typical applications of the enhancement technologies.

In many cases, the information needed to provide a thorough assessment of an application could not be found. For example, the literature does not always discuss the limitations of a technology, or present comparisons with conventional techniques.

The most important criteria for selecting promising heat transfer enhancement applications were undeniable customer benefits, and potential electricity savings. The customer benefits are different for each application, but generally involve one or more of the following:

- reduced operating cost through reduced power consumption,
- reduced capital cost through more compact heat exchanger,
- improvement in product quality,
- faster process and smaller space requirement,
- better control of process temperature.

In addition to the specific benefits of the application, the potential market for the application, and the health of that market are important considerations. Only where a significant number (or size) of industrial sites are known to exist, which meet the requirements of the application, can Ontario Hydro justify the resources to target research activities or encourage replication through technology transfer. Table A1 in Appendix A presents industry sector data which were used to evaluate an industry sector's attractiveness for targeting promising heat transfer enhancement applications.

Only those Ontario industry sectors with identified heat transfer enhancement opportunities are presented in Table A1. The ranking in Table A1 is in descending value of shipments of goods (basis year 1987), with other measures of health shown, such as: value added, growth in value added, number of establishments, and value added per establishment. The data for Table A1 came from the Statistics Canada report "Manufacturing Industries of Canada: National and Provincial Areas" /2/. Figure 7 shows the ranking of the industries by the various criteria.

The value of shipment of goods is a general indicator of the size of the industry. However a more precise indicator of the level of activity in an industry is the value added. The value added is an indicator of the amount of processing performed by an industry, as opposed to the value of shipments which does not distinguish whether an industry just makes minor modifications to refined products.

The number of establishments in an industry is a rough indicator of the replication potential. Although this data does not address the potential number of applications at each site (eg, none or many), it is the best indicator available.

The value added per establishment, and the shipment of goods per establishment represent the capacity of each site to adopt new technologies.

Finally, an indication of the general health of an industry is the growth of the electricity consumption. In general, an industry with strong growth will be in a better position to adopt new technologies. It is curious to note in Table A1 that most of the industries considered in this report experienced negative growth in electricity consumption from 1987 to 1988. It should also be noted that the overall growth in the commercial/industrial sector was 0.4% over the same period.

Value of Shipment of Goods	Value Added
1 - Industrial Organic Chemicals 2 - Aircraft & Aircraft Parts Ind 3 - Industrial Inorganic Chemicals 4 - Motor Vehicle Plastic Parts Ind 5 - Man-Made Fibre & Filament Yarn Ind 6 - Aluminum Rolling, Casting, Extruding 7 - Steel Pipe & Tube Ind 8 - Prepared Flour Mixes & Cereal Foods 9 - Cement Industry 10 - Plastic Pipe & Fittings Ind	1 - Industrial Organic Chemicals 2 - Aircraft & Aircraft Parts Ind 3 - Industrial Inorganic Chemicals 4 - Motor Vehicle Plastic Parts Ind 5 - Man-Made Fibre & Filament Yarn Ind 6 - Aluminum Rolling, Casting, Extruding 7 - Steel Pipe & Tube Ind 8 - Prepared Flour Mixes & Cereal Foods 9 - Cement Industry 10 - Plastic Pipe & Fittings Ind
Number of Establishments	**Intensity of Value Added (ie, $/est)**
1 - Motor Vehicle Plastic Parts Ind 2 - Aircraft & Aircraft Parts Ind 3 - Industrial Inorganic Chemicals 4 - Plastic Pipe & Pipe Fittings Ind 5 - Aluminum Rolling, Casting, Extruding 6 - Industrial Organic Chemicals 7 - Steel Pipe & Tube Ind 8 - Man Made Fibre & Filament Yarn Ind 9 - Prepared Flour Mixes & Cereal Foods 10 - Cement Industry	1 - Cement Industry 2 - Prepared Flour Mixes & Cereal Foods 3 - Industrial Organic Chemicals 4 - Man Made Fibre & Filament Yarn Ind 5 - Industrial Inorganic Chemicals 6 - Steel Pipe & Tube Ind 7 - Aircraft & Aircraft Parts Ind 8 - Aluminum Rolling, Casting, Extruding 9 - Motor Vehicle Plastic Parts Ind 10 - Plastic Pipe & Pipe Fittings Ind
Intensity of Value of Shipments (ie, $/est)	**Growth in Electricity Consumption**
1 - Industrial Organic Chemicals 2 - Prepared Flour Mixes & Cereal Foods 3 - Man-Made Fibre & Filament Yarn 4 - Cement Industry 5 - Steel Pipe & Tube Ind 6 - Industrial Inorganic Chemicals 7 - Aluminum Rolling, Casting, Extruding 8 - Aircraft & Aircraft Parts Ind 9 - Motor Vehicle Plastic Parts Ind 10 - Plastic Pipe & Pipe Fittings Ind	1 - Industrial Organic Chemicals 2 - Industrial Inorganic Chemicals 3 - Man-Made Fibre & Filament Yarn Ind 4 - Cement Industry 5 - Prepared Flour Mixes & Cereal Foods 6 - Motor Vehicle Plastic Parts Ind 7 - Steel Pipe & Tube Ind 8 - Aircraft & Aircraft Parts Ind 9 - Plastic Pipe & Pipe Fittings Ind 10 - Aluminum Rolling, Casting, Extruding

Figure 7 - Ranking of Industries with Heat Transfer Enhancement Opportunities

3 PROMISING HEAT TRANSFER ENHANCEMENT APPLICATIONS

Using the selection criteria outlined in the previous section, the most promising heat transfer enhancement applications were selected from the 15 applications outlined in Appendix A. The applications are summarized as either technology transfer opportunities, or research and development opportunities.

3.1 Technology Transfer Opportunities

Technology transfer opportunities include the applications which can be directly applied in Ontario industry. The main requirement for the application will typically involve providing information in an existing or revised format.

3.1.1 High Flux Tubing for Ethylene Column Condenser

UOP's High Flux tubing uses a porous metal coating on the tubing to provide dramatic enhancements in boiling and condensing. A sketch of the tubing cross section was shown in Figure 3. There are a number of different applications for the tubing in ethylene plants, however the condenser application was chosen to illustrate the benefits.

High Flux tubing allows boiling to occur at much smaller temperature differences than with conventional smooth tubing. The lower temperature difference puts less demand on the compressor and thus provides significant power savings. For example, in an ethylene plant producing 450 tonnes per year, High Flux tubing would use 64% less compressor power (a reduction of 900 kW) than the same area of conventional tubing with the same heat transfer /8/.
The industrial segment for this application is Industrial Organic Chemicals which had the largest value added, largest value of shipment of goods, and largest value of shipment of goods per establishment for the industries listed in Table 1. Since the High Flux tubing was developed by Union Carbide, it has seen many applications at the Union Carbide plants. Therefore, new applications will more likely occur at other manufacturers' plants.

The High Flux tubing has been quite extensively used internationally since 1971 (a list of approximately 200 applications was provided by the manufacturer). The technology therefore has a considerable amount of operating experience to draw upon.

3.1.2 Infrasonic Cooling or Heating of Plastic Pellets

Infrasonik Inc. produces an infrasound system for cooling plastic pellets. The oscillating air flow provides a high rate of heat transfer and creates a fluidized bed of the pellets. There are two different techniques used to provide the cooling and heating; introducing cooled or heated air to the process, and utilizing cooling or heating tubes in the chamber. A sketch of the system which uses cooling or heating tubes in the process was shown in Figure 2. The pellets progress through the process on stationary screens which are inclined so that gravity moves the pellets along.

The industry category that would use the plastic pellet cooler is the man-made fibre and filament yarn industry. Of the industries listed in this study, the fibre and filament industry was the fifth largest in value added and fourth largest in value added per establishment.

An infrasonic pellet cooler is operating in Sweden where it has allowed the process power consumption to be reduced from 41 kW to 16.5 kW /9/. In addition to the power savings, a shorter residence time was achieved which improved the product quality.

3.1.3 Air-Jet Cooling/Toasting of Cereal

In the Prepared Flour Mixes and Cereal Foods industry, the conventional method for toasting, puffing, drying, and cooling cereals is in forced convection ovens. An air-jet system produced by Wolverine Corporation (Jetzone system) heats and cools cereal with air impinging on the cereal which also creates a fluidized bed. A sketch of the air-jet system is shown in Figure 1(a). Compared to the conventional ovens, the air-jet system provides a more uniform air temperature and therefore a more uniform product temperature and quality. Also, there is less abrasion and breakage, which increases the product yield.

According to the manufacturer of the air-jet system (Wolverine Corporation), there are a considerable number of these systems installed in the U.S. cereal industry (they did not have information on Canadian industry). In addition to the cereal industry, the technology would be applicable to a number of other processes. The product literature lists a number of other materials that can be processed with the system, such as metal particles, salts, plastic pellets, and food pellets.

One uncertainty about this technology is how much electricity is required in comparison to the conventional technologies. This issue could be addressed as a potential application arises.

3.2 Research and Development Opportunities

Research and development opportunities include the applications which will require some evaluation of specific parameters in order to lessen the risk that would be taken by the end user. The research and development opportunities also include applications where development could improve the benefit to Ontario Hydro (eg, maximizing the load reduction potential).

3.2.1 Infrasonic Cooling of Clinkers in the Cement Industry

In the production of cement, a kiln is used to fuse the raw materials into lumps, or "clinkers". The kiln is the greatest consumer of fuel in a cement plant and one of the most wasteful consumers of fuel /10/. After being fused, the clinkers are cooled using large blowers. In a development project in England, infrasound is being used for both combustion enhancement and clinker cooling at a cement plant. The preliminary indications are that combustion is significantly improved, fan air flow can be reduced, and the production of the unit is increased. However, the process is still in development and data from the project is scarce.

Among the industries listed in this report, the cement industry had the largest intensity of value added (ie, value added per establishment). The cement industry also had the second lowest total value added. However, the energy and electricity costs represent a large portion of the total value added, which makes the cement industry a good target for load reduction opportunities.

The research opportunity with clinker cooling would involve an assessment of the technology at a site in Ontario. The first step would be to identify an end user interested in following up the application. The next step could involve two possible levels of activity: 1) monitoring the results from the project in

England, and 2) build on these results and assist an Ontario cement manufacturer in developing the process.

3.2.2 Tube Inserts for Air Cooled Lube Oil Cooler

In a power plant, the turbine lubricating oil must be cooled to keep it below a certain temperature. In air-cooled heat exchangers for cooling lube oil, the oil provides the greater resistance to heat transfer and therefore tube inserts can provide a significant improvement in heat exchanger performance. Cal Gavin Limited produces a wire matrix insert which can be used to improve heat transfer such that the size of an oil cooler can be considerably reduced, and the fan power consumption can be reduced from 12 kW to 5 kW (for heat duty of 373 kW).

In Ontario, the main applications for the oil cooler enhancement will be within Ontario Hydro. Inserts have also been used for cooling transformer oil, and other viscous liquids such as chocolate.

The research required in this application is to determine which type of insert can provide the largest heat transfer enhancement per unit of power required. Webb /4/ has suggested that twisted tape inserts will provide more heat transfer per unit of friction in laminar flow. However, there does not appear to be any published experimental evidence to directly support this claim. Also, the heat transfer per unit of friction is not an accurate indication of the heat transfer per unit of power.

4 CONCLUSIONS

There are a large number of heat transfer processes in Ontario industry which could use enhancement techniques to increase productivity and reduce power consumption. The enhancement techniques will have an impact on the fan and pump load used in heat exchangers and materials processing (approximately 510 MW). A total of 15 applications were summarized in this report to typify the opportunities for heat transfer enhancement that are commercially available.

Five heat transfer enhancement applications were selected on the basis of their benefit to the customer, the load reduction potential, and the potential for application across many industries. The opportunities were categorized as being either technology transfer or research and development opportunities.

The study identified the following technology transfer opportunities:

- High Flux tubing for ethylene column condenser;
- Infrasonic cooling or heating of plastic pellets;
- Air-jet cooling or heating of cereal.

The following opportunities for research and development were identified:

- Infrasonic cooling of cement clinkers;
- Tube inserts for air-cooled lube oil cooler.

It is expected that the five specific opportunities listed above will provide a considerable benefit to Ontario Hydro and its customers. Also, a much larger potential exists by utilizing the technologies in similar applications in other industries.

5 RECOMMENDATIONS

1. The technology transfer opportunities identified in section 3 should be followed up in two stages:

   i) substantiated data should be obtained to verify the benefits claimed in the literature;

   ii) case studies should be prepared to summarize the benefits of the applications in a format which is useful to the regional representative.

2. For the two research and development opportunities, the first step will be to find an end user interested in pursuing the opportunity.

   The clinker cooling application should then be pursued by monitoring the developments at the application in England. If there is sufficient interest from the end user, the next step would be a field trial.

   The lube oil cooling application should be followed up by reviewing the literature to determine if there is enough experimental evidence to determine which insert provides the most heat transfer per unit of pumping power. If there is not enough information in the literature, then small scale tests should be performed on the various inserts to measure their relative performances. This work could either be performed at Ontario Hydro's Research Division, or contracted out to a university depending on the availability of resources.

3. There is very little information in the literature about the power requirements of air-jet impingement processes. This information gap presents a bottleneck in terms of assessing the value of air-jet impingement for Ontario Hydro's demand management programs.

   The power requirements should therefore be assessed (ie, heat transfer per unit of power) through either the published literature (if sufficient) or lab tests. This work could be performed either at Ontario Hydro's Research Division or at a university laboratory.

4. It is recommended that a joint project be performed with Ontario Hydro's Research Division and the manufacturer of infrasound equipment (Infrasonik Inc) to develop a laboratory unit which can demonstrate the benefits of infrasound. The small scale unit will lower the end user's cost for evaluating an infrasound process.

5. A study should be performed to outline the opportunities for enhancing drying processes in Ontario industry. The drying enhancement study would complement the earlier study of electromagnetic drying techniques.

6. A working group should be set up within Ontario Hydro to exchange information about heat transfer enhancement technologies. Participants could come from a number of branches including Energy Management and Corporate Relations, Design and Construction, Regions, and Environment and Corporate Planning.

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6 REFERENCES

1] Bergles A.E., "Some Perspectives on Enhanced Heat Transfer - Second-Generation Heat Transfer Technology", Journal of Heat Transfer, pg. 1082, vol. 110, November 1988.

2] "1987 Manufacturing Industries of Canada: National and Provincial Areas", Statistics Canada report number 31-203, 1990.

3] Woods B.G., "Motor Use and Overall End Use of Electricity by Ontario Industry", Ontario Hydro Research Division Report #90-246-K, January 16, 1991.

4] Webb R.L., "Special Surface Geometries for Heat Transfer Augmentation", pg. 179, in Developments in Heat Exchanger Technology - 1, ed. D. Chisholm, Applied Science Publishers Ltd, London, 1980.

5] Woods B.G., "Electrical Load Reduction Via Infrasonic Enhancement of Process Heat Transfer", Ontario Hydro Research Division Report #91-68-K, May 29, 1991.

6] Webb R.L., "A Parametric Analysis of the Performance of Internally Finned Tubes for Heat Exchanger Application", Advances in Enhanced Heat Transfer, 18th National Heat Transfer Conference, pg. 69, San Diego California, 1979.

7] Menon A.S., Mujumdar A.S., "Drying of Solids: Principles, Classification, and Selection of Dryers", pg. 3 in Handbook of Industrial Drying, ed. Arun S. Mujumdar, Marcel Dekker Inc., New York, 1987.

8] Antonelli R., "Application of Advanced Heat Transfer Technology to the Chemical Process Industry and Consequent Energy Savings", presented at the VI Convencion Nacional de la Industria Quimica, Madrid Spain, Dec 1-3, 1976.

9] Correspondence with Bruce Yearham, Kiln Technology Ltd., January 11, 1991.

10] Witt J.C., Portland Cement Technology, Chemical Publishing Company, New York., 1966.

11] Wolverine Corporation Jetzone literature.

12] "Moen Data Bulletin - Filament Winding", product literature for Heat Transfer Technologies Inc.

13] "Wolverine Filament Processors", Product literature from Wolverine Corporation, Merrimac, Ma.

14] Air Blast Inc., Product Literature, San Gabriel, California.

15] Malingren N.G., "Recent Development in Controlled Cooling Systems for Wire Rod - Infrasonic Cooling", Iron and Steel Engineer, pg. 45, January 1991.

16] Lai J.L., Jartt G.N., "Future of SMC Body Panels", Automotive Polymers and Design, pg. 23, February 1990.

17] Arora V.K., Wilk J.F., "Use of High Velocity Hot Air Impingement to Cure Structural Adhesives", SAE paper 890244.

18] Aukerman R.W., Lewis S.D., "The 'Moen' Real Time Heating System for Curing and Forming 350°C Resin and 700°C Thermoplastic Composites", presented at Composites in Manufacturing 5, Jan 13-16, 1986, Los Angeles California.

19] Correspondence with Bruce Yearham, Kiln Technology, October 3, 1991.

20] Ragi E.G., Weiler D.W., Wolf C.W., "Energy Costs Prompt Improved Distillation", The Oil and Gas Journal, September 1, 1975.

21] Siddiqui M.I.R., Mir A., "Vibration Free Rod Baffle Design of Tube Bundle for Boiler Feed Water Preheater Increases Ammonia Plant On-Stream Time", presented at the American Institute of Chemical Engineers Ammonia Safety Symposium, November 5-8, 1989, San Francisco, U.S.A.

22] Rebello W.J., "Assessment of Heat Transfer Enhancement and Fouling in Industrial Heat Exchangers", U.S. DOE report #DOE/CE/40716-3, November 1987.

23] "HiTRAN Technology reduces size and fan power for new air cooled oil cooler", Project Report 3, product literature from Cal Gavin Limited, England.

APPENDIX A

Summary of Contents:

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TABLE A1 - Economic Data For Industrial Sectors with Heat Transfer Enhancement Applications

SIC code	Industry Sector	Value of Shipments of Goods ($'000)	Value Added ($'000)	Growth in Electricity Consumption*	Number of Establishments	Intensity of Value Added ($000/est.)
3712	Industrial Organic Chemicals	3,033,626	956,168	9.4%	30	31872
3211	Aircraft & Aircraft Parts Ind	1,442,859	751,464	-4.4%	63	11928
3711	Industrial Inorganic Chemicals	1,221,467	688,666	-0.6%	41	16796
3256	Motor Vehicle Plastic Parts Ind	1,119,061	499,849	-3.3%	75	6664
1811	Man-Made Fibre & Filament Yarn Ind	1,004,544	465,764	-0.9%	16	29110
2961	Aluminum Rolling, Casting, Extruding	878,524	292,187	-4.5%	32	9130
2921	Steel Pipe & Tube Ind	761,411	230,280	-3.4%	18	12793
1052	Prepared Flour Mixes & Cereal Foods	650,383	357,559	-2.5%	10	35756
3521	Cement Industry	435,552	262,398	-1.2%	7	37485
1621	Plastic Pipe & Pipe Fittings Ind	366,865	137,789	-4.4%	36	3827

1987 data published by Statscan in 31-203 in 1990
* growth from 1987 to 1988

TABLE A2 - Summary of Heat Transfer Enhancement Applications

Food and Beverage Industry (10,11)	Primary Metals Industry (29)	Chemical & Chemical Products Ind (37)
1- Toasting/Cooling Cereal (AJI) 2- Processing of Cereal Snacks (AJI)	6- Cooling of Sheet Aluminum (ASI) 7- Cooling of Wire Rod (IS)	11- Reboiler/Condenser for C_3 splitter (HFT) 12- Ethylene Column Condenser (HFT) 13- Boiler Feed Water Pre-Heater, Ammonia Plant (RBHX) 14- Distillation Column in Air Separation Plant (HFT2)
Plastic Products Industries (16)	**Transportation Equipment Ind. (32)**	**Electric Power Generation**
3- Heating of mandrel for filament winding (AJI)	8- Curing of Structural Adhesives (AJI) 9- Curing/Forming of Thermoplastic Composites (AJI)	15- Air-cooled lube oil cooler (CWI)
Primary Textiles Industries (18)	**Non-Metallic Mineral Products Ind (35)**	LEGEND: AJI = air-jet impingement ASI = air-slot impingement IS = infrasound HFT = High Flux Tubing HFT2= doubly enhanced High Flux tubing RBHX= RODbaffle heat exchanger CWI = coiled wire inserts
4- Heating/Cooling finishing resins on filaments (ASI) 5- Cooling of Plastic Pellets (IS)	10- Clinker Cooling (IS)	

Table A3 - Food and Beverage Industry

Applications (SIC Code)	Toasting/Cooling Cereal (1052)	Processing of Cereal Snacks (1052)
Description of application?	air-jets use heated or cooled air to create a fluidized bed with cereal	air jets use heated air to cook food
How currently done in industry?	convection oven	frying in oil
What technology is used?	air-jet impingement/fluid bed	air-jet impingement / fluid bed
Industrial application status	many installations	many installations
Benefit(s) of the Technology	- lower operating costs - less breakage of product - uniformity of product and precise temperature control	- lower calories because oil is not used - lower operating costs - less breakage of product - uniformity of product and precise temperature control
Limitation(s) of the Technology	- power consumption not known for process	- power consumption not known for process
R&D Needs	- determine power requirement of air-jet impingement	- determine power requirement of air-jet impingement
Technology Transfer Needs	investigate the potential in similar processes	investigate the potential in similar processes
Potential in Ontario (number of establishments)	(10)	(10)
References	(11)	(11)
Allies	Wolverine Corp, Dr. A. Mujumdar (McGill Univ.)	Wolverine Corp, Dr. A. Mujumdar (McGill Univ.)

Table A4 - Plastic Products Industries

Applications (SIC Code)	Heating of Mandrel for Filament Winding (1621)
Description of application?	air-jet heating of inside of mandrel for thermoset & thermoplastic composites
How currently done in industry?	strip heaters, ovens, or autoclaves
What technology is used?	air-jet impingement
Industrial application status	at least two applications in North America
Benefit(s) of the Technology	- quicker thermal response - better temperature control - mandrel temperature within 2.5°C of "soak" temperature
Limitation(s) of the Technology	- no data on electricity consumption (claims to require less "energy")
R&D Needs	assess power requirements of air-jet impingement
Technology Transfer Needs	
Potential in Ontario (number of establishments)	(37)
References	(12)
Allies	Proquip Consultants, Heat Transfer Technologies Inc., Dr. Mujumdar (McGill Univ.)

Table A5 - Primary Textiles Industries

Applications (SIC Code)	Heating/Cooling Finishing Resins on Filaments (1811)	Cooling of Plastic Pellets (1811)
Description of application?	slot-impingement for curing, heat setting or cooling resins on filaments	cooling of plastic pellets and granules
How currently done in industry?	forced convection (blowers)	forced convection (blowers)
What technology is used?	slot-impingement of heated or cool air	infrasound
Industrial application status	numerous installations in U.S.	2 systems operating in Sweden
Benefit(s) of the Technology	- good control of temperature and speed of process - fast process time	- process power reduced by 60% - better product quality due to reduction in residence time - less demand on air filter (ie. less net air flow) and also less wear on product from dust
Limitation(s) of the Technology	- power requirement of system not known	- higher capital cost than fan system
R&D Needs	- investigate the electrical efficiency of slot jet impingement	- develop small scale unit for process development - investigate most efficient means for generating infrasound
Technology Transfer Needs	- summarize application information in a case study	- summarize application information in a case study
Potential in Ontario (number of establishments)	(16)	(16)
References	(13)	(9)
Allies	Wolverine Corp., Dr. Mujumdar (McGill Univ.)	Infrasonik Inc, Kiln Technology Ltd

Table A6 - Primary Metal Industries

Applications (SIC Code)	Cooling of Sheet Aluminum (2961)	Cooling of Wire Rod (2921)
Description of application?	Cooling sheet aluminum (.18 mm. thick)	cooling wire rod with a combination of infrasound and blowers
How currently done in industry?	forced convection (blowers)	forced convection (blowers)
What technology is used?	slot impingement	infrasound
Industrial application status	installed in U.S.	units installed in Norway, Sweden, and Finland
Benefit(s) of the Technology	- high cooling rate	- improved product quality due to a more uniform of cooling around the rod - reduction in process power consumption of 60% to 80% - exhaust air is at a useful temperature for heat recovery
Limitation(s) of the Technology	- best with a material like aluminum which has a high thermal conductivity	- not clear whether cooling rate will be high enough to make large scale applications feasible (process dropped by Swedish company but picked up by Japanese companies) - higher capital cost than fan system
R&D Needs	- investigate electrical efficiency of air jet impingement for convection	- establish feasibility of full scale process - develop small scale infrasound unit for evaluation of similar processes
Technology Transfer Needs	- summarize application information in a case study	- document details of specific sites where it has been used
Potential in Ontario (number of establishments)	(33)	(26)
References	(14)	(15)
Allies	Air Blast Inc., Dr. Mujumdar (McGill Univ.)	Infrasonik Inc, Kiln Technology Inc.

Table A7 - Transportation Equipment Industries

Applications (SIC Code)	Curing of Structural Adhesives (3256)	Curing/Forming of Thermoplastic Composites (3211)
Description of application?	bonding sheet molded panels	curing/forming of thermoplastic composites in the aircraft industry
How currently done in industry?	contact heating	oven or autoclave
What technology is used?	air-jet impingement	air-jet impingement
Industrial application status	at least 5 applications in North America	applied in aircraft industry
Benefit(s) of the Technology	- fast curing (20-30 seconds, as compared to radiofrequency cure time of 45-60 seconds - less costly than radiofrequency - energy costs expected to be reduced by 60% /7/	- faster heating - better control over heating - reduces energy consumption (no data provided)
Limitation(s) of the Technology	- process time limited by thermal conductivity of adhesive (to avoid foaming)	- different air distribution network needed for each different shaped part
R&D Needs	- investigate relative electrical requirements of air jet impingement	- investigate relative electrical requirement of air-jet impingement
Technology Transfer Needs	- summarize application information in a case study	- summarize application information in a case study
Potential in Ontario (number of establishments)	(73)	(75)
References	(16),(17)	(8)
Allies	Proquip Consultants, Heat Transfer Technologies Inc., Dr. Mujumdar (McGill Univ.)	Proquip Consultants, Heat Transfer Technologies Inc., Dr. Mujumdar (McGill Univ.)

Table A8 - Non-Metallic Mineral Products Industries

Applications (SIC Code)	Clinker Cooling (3521)
Description of application?	cooling of clinkers in cement production
How currently done in industry?	forced convection (blowers)
What technology is used?	infrasound
Industrial application status	pilot plant installed in U.K.
Benefit(s) of the Technology	- less fan power required - reduction in fuel requirement - increase in productivity - less filtering required in electrostatic precipitators
Limitation(s) of the Technology	- new development, therefore application data is scarce
R&D Needs	-investigate the best placement and infrasound intensity for the application - develop a small scale unit for process development
Technology Transfer Needs	document the available information
Potential in Ontario (number of establishments)	(7)
References	(19)
Allies	Infrasonik Inc, Kiln Technology Ltd.

Table A9a - Chemical & Chemical Products Industries

Applications (SIC Code)	Reboiler/Condenser for C_3 Splitter (3712)	Ethylene Column Condenser (3712)	Boiler Feed Water Pre-heater, Ammonia plant (3711)
Description of application?	reboiler/condenser of a distillation system for separation of propylene & propane	ethylene column (or C_2 splitter) condenser	boiler feed water pre-heater
How currently done in industry?	smooth tube heat exchangers	smooth tube heat exchangers	shell & tube heat exchangers with double segmented baffles
What technology is used?	High Flux Tubing (bonded porous metal layer on tubes)	High Flux Tubing (bonded porous metal layer on tubes)	RodBaffle shell & tube heat exchangers
Industrial application status	5 applications installed since 1980	38 applications internationally	installed in 1987 (Pakistan)
Benefit(s) of the Technology	- for same heat exchanger area, compressor power can be reduced by 45% - at the expense of the power savings, heat exchanger size can be reduced	- for the same heat exchanger area, compressor power can be reduced by 64% - at the expense of the power savings, heat exchanger size can be reduced	- eliminated leakage/vibration problems in old heat exchangers - improved heat transfer - shell side pumping power reduced by 50% (tube side power slightly reduced)
Limitation(s) of the Technology	- used primarily for boiling and condensing heat transfer	- used primarily for boiling and condensing heat transfer	
R&D Needs			
Technology Transfer Needs	- investigate tradeoff between capital cost and power savings for each application	- investigate tradeoff between capital cost and power savings for each application	- summarize application data in a case study
Potential in Ontario (number of establishments)	(27)	(27)	(35)
References	(20)	(8)	(21)
Allies	UOP Canada Inc.,	UOP Canada Inc.	Phillips Petroleum Co.,

Table A9b - Chemical & Chemical Products Industries

Applications (SIC Code)	Distillation Column in Air Separation Plant (3711)
Description of application?	separation of air into oxygen, nitrogen and other gases by low temperature distillation
How currently done in industry?	plate-fin heat exchangers
What technology is used?	doubly enhanced high flux tubing (porous metal layer inside, longitudinal splines outside)
Industrial application status	installed in two 2000 ton/day plants since 1978
Benefit(s) of the Technology	- higher heat transfer per volume of heat exchanger - compressor power consumption reduced by 50% (15 MW reduction in a 2000 ton/day plant)
Limitation(s) of the Technology	- used primarily for boiling and condensing heat transfer
R&D Needs	
Technology Transfer Needs	- investigate the tradeoff between capital cost and power savings
Potential in Ontario (number of establishments)	(35)
References	(22)
Allies	UOP Canada Inc

Table A10 - Electric Power Generation Industry

Applications (SIC Code)	Air Cooled Lube Oil Cooler
Description of application?	cooling turbine lube oil from 85°C to 71°C
How currently done in industry?	plain finned tube
What technology is used?	coiled wire inserts
Industrial application status	specific case was a design proposal (a number of oil coolers are installed)
Benefit(s) of the Technology	- fan power reduced by 58% - smaller size - smaller capital and operating cost
Limitation(s) of the Technology	- inserts work best when thermal resistance of viscous fluid limits the amount of heat transfer
R&D Needs	assess which insert has the best performance
Technology Transfer Needs	transfer of information
Potential in Ontario *(number of establishments)*	
References	(23)
Allies	Cal Gavin Ltd.

APPENDIX B

List of Manufactures

Air-Jet and Slot Impingement

1) Air Blast Inc., San Gabriel California, phone (818) 576-0144
2) Glenro Inc., Patterson New Jersey, phone (201) 279-5900
3) Heat Transfer Technologies Inc., Encino California - distributed in Canada by Proquip Consultants Inc., phone (416) 254-0432
4) Nortel Mfg. Ltd., Scarborough Ontario, phone (416) 438-3325
5) Paxton Products Inc., Santa Monica California, phone (213) 450-4800
6) Sonic Air Systems, Santa Fe Springs California, phone (213) 941-0254
7) Vortec Corporation, Cincinnati, Ohio, phone (513) 891-7474
8) Wolverine Corporation, Merrimac Massachusetts, phone (508) 346-4541

Tube Inserts for Heat Exchangers

1) Brown Fintube Company, Houston Texas, (713) 466-3535
2) Cal Gavin Process Intensification Engineering, Birmingham England, phone 44 21 440 0111
3) Chemineer, Kenics Static Mixers, Dayton Ohio, distributed in Canada by Archem Process Equipment Ltd., phone (416) 528-6857
4) Koch Engineering Company Ltd., Wichita Kansas, distributed in Canada by Romatec, Willowdale Ontario, phone (416) 499-0222
5) Ross Engineering Inc., Savannah Georgia, phone (912) 238-3300

Enhanced Tubing for Heat Exchangers

1) Delta T Ltd., Tulsa Oklahoma, phone (918) 584-0314
2) Escoa Division Fintube Corp., Pryor Oklahoma, (918) 825-2966
3) High Performance Tube Inc., Union New Jersey, phone (908) 964-8520
4) ITT Standard, Mississauga Ontario, phone (416) 890-6155
5) Turbotec Products Inc., Windsor Connecticut, phone (203) 683-2005
6) Unifin International, London Ontario, (519) 451-0230
7) UOP Canada Inc. (High Flux Tubing), Toronto Ontario, phone (416) 322-1616
8) Wieland Metals Canada Ltd., Islington Ontario, phone (416) 232-0451
9) Wolverine Tube Inc., Decatur Alabama, phone (205) 353-1310

Infrasound

1) Infrasonik Inc., Kirkland Washington, distributed in Canada by Kiln Technology Ltd., (416) 570-0211

Miscellaneous

1) RODbaffle Heat Exchangers, Phillips Petroleum Company, Bartlesville Oklahoma, phone (918) 661-0625